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Properties of magnetoelastics synthesized in external magnetic field

L.V. Nikitin[a,*], G.V. Stepanov[b], L.S. Mironova[a], A.N. Samus[a]

[a] *Physical Department, Moscow State University, Moscow 119899, Russia*
[b] *State Research Institute of Chemistry and Technology of Organoelement Compounds, Sh. Entuziastov 38, Moscow 111123 Russia*

Abstract

In the present work we consider new magnetocontrolled elastic composite materials (magnetoelastics) produced by dispersing ultra-fine and larger magnetic particles in polymer matrix based on natural or synthetic rubber. The influence of conditions of magnetoelastics synthesis (with or without magnetic field) on change of their shape in a magnetic field is under consideration. It is revealed that the formation of chains of magnetic particles in a magnetic field during samples synthesis results in anisotropy of magnetic and elastic properties.

Keywords: Smart materials; Magnetoelastic; Magnetic and elastic properties

1. Introduction

It is known that the magnetic particles in magnetic dispersion are aligned into chains by applied magnetic field during magnetoelastic curing. This phenomenon results in anisotropy of magnetic and elastic properties, in appearance axes of easy and hard magnetization and in various behaviour of samples in external magnetic field. In the present work we consider new magnetocontrolled elastic composite materials (magnetoelastic) [1–4] produced by dispersing ultra-fine and larger magnetic particles (from 10 nm to 3 μm) in polymer matrix based on natural or synthetic rubber and liquid organic components synthesized in external magnetic field. It was found that in magnetic field these materials (called smart materials) have large value of elongation (several hundred percents) and after elongation they completely restore their original shape when we turned off magnetic field.

2. Results and discussion

Investigating behaviour thin magnetoelastic ribbon in nonuniform and uniform magnetic fields we found that shape of sample depends on configuration of magnetic field, and anisotropy magnetic and elastic properties of sample. For example, Fig. 1 gives the behaviour of thin ribbon magnetoelastic placed in a nonuniform magnetic field. Ribbon was synthesized in a magnetic field directed along the width of sample. During synthesis the magnetic particles lined up along a magnetic field and formed magnetic clusters with anisotropy of magnetic properties. Smooth motion of the fastened upper end of ribbon along the perimeter of permanent magnet results in rotation of the bottom free end. The change of a direction of magnetic leakage field of permanent magnet results in rotation of the bottom end of ribbon, because the increase of the elastic energy compensates the decrease of magnetic energy. In this case angle of twisting γ may be found from equation

$$\mathrm{CLBM}\sin(\alpha-\gamma)-\gamma=0, \tag{1}$$

where the parameter C is defined by properties of magnetoelastic material, L is length of a sample, B is magnetic induction, M is magnetic moment of the bottom free end of ribbon and α angle between B and initial direction (without magnetic field) of axis of easy magnetization.

If twisting ribbon with the two fastened ends will be placed in uniform magnetic field so that the angle of twisting is 180° and the magnetic field is directed along

*Corresponding author. Tel.: +7-095-939-38-47; fax: +7-095-939-47-87.
E-mail address: nikitin@magn.ru (L.V. Nikitin).

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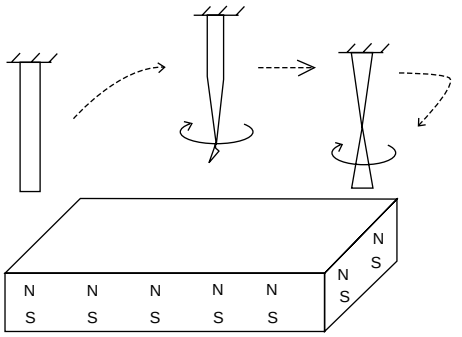

Fig. 1. The scheme of change of shape for magnetoelastic in field of permanent magnet.

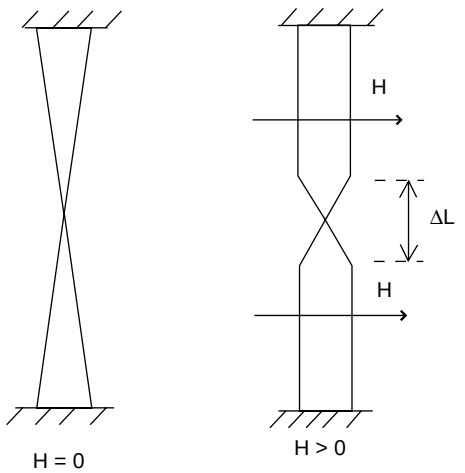

Fig. 2. The scheme of change of shape for twisted magnetoelastic, placed in uniform magnetic field.

the width of the two fastened ends, then value of uniform magnetic field will influence length ΔL of the twisting region. Fig. 2 shows the change of the shape magnetoelastic ribbon synthesized in a uniform magnetic field directed along the width of a sample (angle of twisting is 180°). When uniform magnetic field is absent the angle of twisting changes along all length of a sample uniformly. In uniform magnetic field, the length ΔL of twisting region decreases with increasing of value of a magnetic field. For the same value of magnetic field we have the same equilibrium length ΔL of twisting region as a result of minimization of the sum of magnetic and elastic energy.

In this case elastic energy can be given as

$$W_{\mathrm{el}} = \gamma^2/2C\Delta L \tag{2}$$

and energy of interaction with magnetic field can be written as

$$W_{\mathrm{magn}} = -\sigma_1(L - \Delta L) - \sigma_2\Delta L, \tag{3}$$

where σ_1 and σ_2 are specific energies along the length of sample in plane and twisting regions of ribbon, accordingly. Length ΔL of twisting region can be found by minimization of the sum of magnetic and elastic energy with respect to ΔL. One can see that the length ΔL of twisting region is

$$\Delta L = \sqrt{\frac{\gamma^2}{2C(\sigma_1 - \sigma_2)}}, \tag{4}$$

where value $(\sigma_1 - \sigma_2)$ is function of magnetization and magnetic field.

The behaviour of samples with square section in uniform magnetic field is demonstrated in Fig. 3. The samples were polymerized in a uniform magnetic field directed along or across its length.

The shape of all samples without a magnetic field (polymerized in along or across magnetic field) is represented in Fig. 3a. One can see that samples hang vertically downwards. However, in a magnetic field samples behave in different ways. The sample with orientation of magnetic particles chains along the length bend (see Fig. 3b) and increase its length as a result of

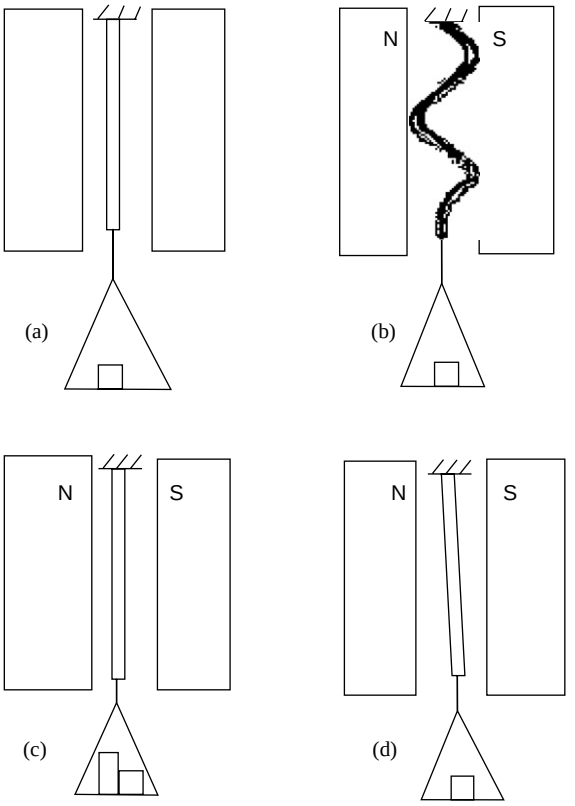

Fig. 3. The scheme of behaviour of magnetoelastics manufactured in magnetic field applied along and across length of sample.

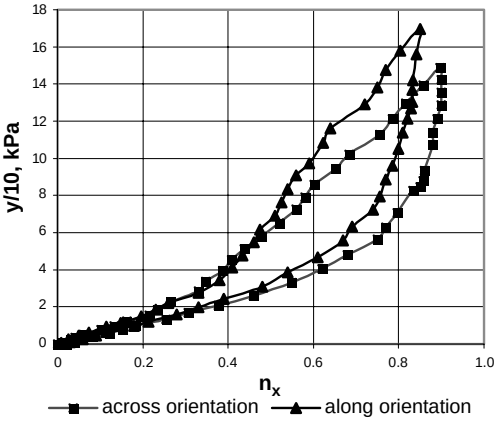

Fig. 4. Dependence of the elastic stress σ on the relative elongation ΔX for magnetoelastics, on the basis of iron particles.

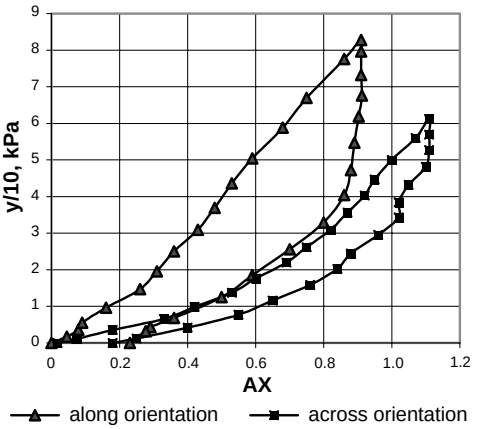

Fig. 5. Dependence of the elastic stress σ on the relative elongation ΔX for magnetoelastics on the basis of needle-shaped γ-Fe_2O_3 particles.

several bends in uniform magnetic field. When we load this sample with longitudinal axis of easy magnetization and the stretched force increases the sample shape takes the initial shape (see Fig. 3c). The sample with across orientation of axis of easy magnetization keeps its initial (see Fig. 3a and 3d) shape because its axis of easy magnetization is parallel to a direction of the external magnetic field.

Also it was found that Young's modulus for these samples measured for force F parallel to chains is larger than Young's modulus for the same samples measured for F perpendicular towards chains. Besides both moduli increase in magnetic field. As example, Figs. 4 and 5 give the dependences of elastic stress σ on relative elongation Δx for two magnetoelastics on the basis of spherical particles of iron with size 2 μm (Fig. 4) and needle-shaped γ-Fe_2O_3 particles with length 0.5 μm (Fig. 5) synthesized in magnetic field. One can see, that the influence of a magnetic field on mechanical properties is larger in a case of needle-shaped γ-Fe_2O_3 particles and the dependences of stress σ on relative elongation Δx have hysteresis character.

3. Conclusions

Thus, it is shown that the magnetic field applied to magnetoelastic sample during curing influences on following behaviour, the elastic properties and shape of samples in the magnetic field. This fact is very important for techniques. It is found that elastic properties along and across magnetic field of curing are differed.

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